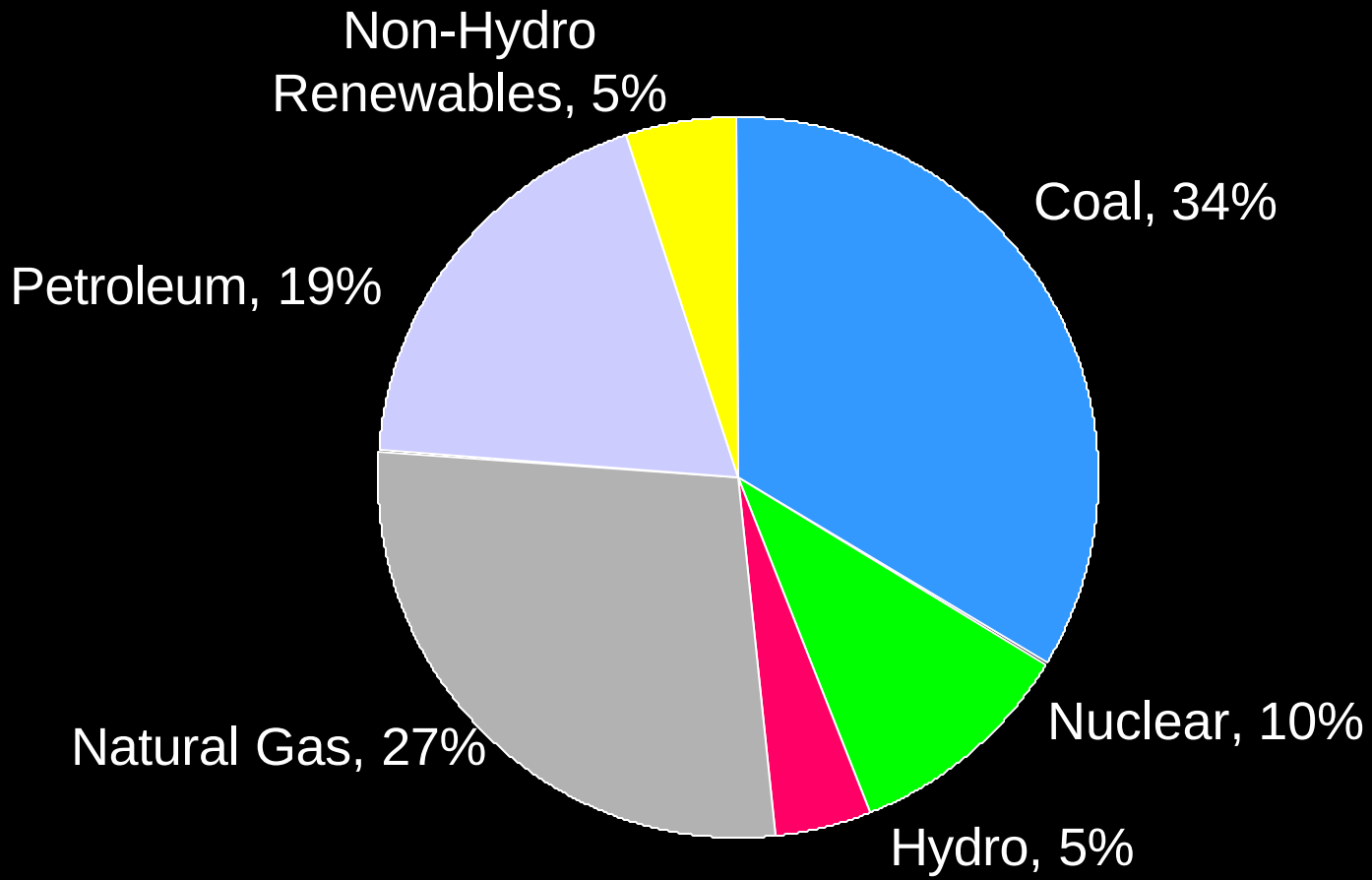
NREL
National Renewable Energy Laboratory

Renewable Energy Technology Status

Stanley R. Bull
National Renewable Energy Laboratory

Presented to
Army WEEC 2000
December 6, 2000

U.S. Energy Production by Source, 1998



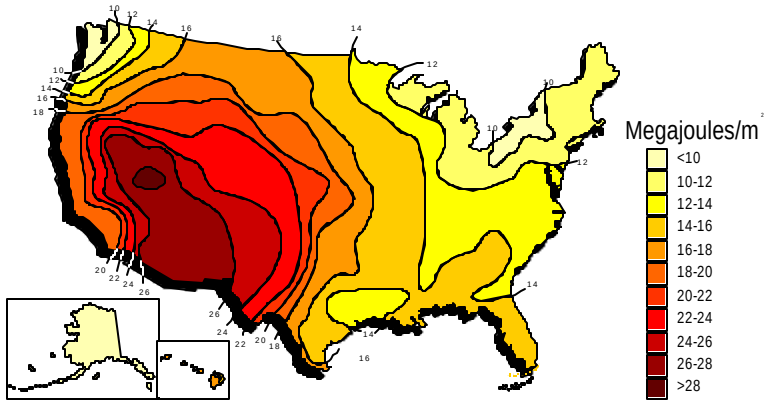
Source: *Annual Energy Review 1998*, Table 1.2

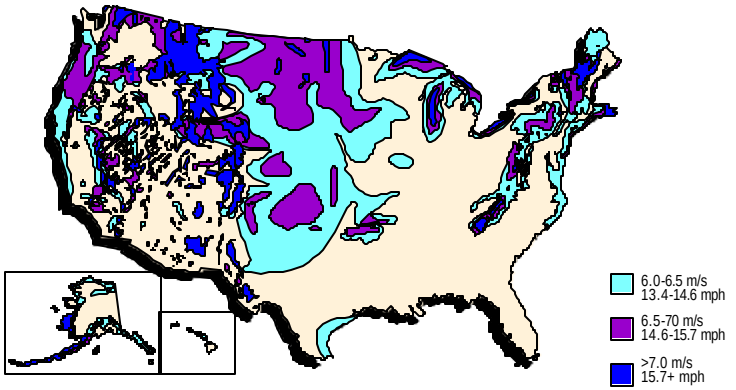
Renewable Energy Pathways

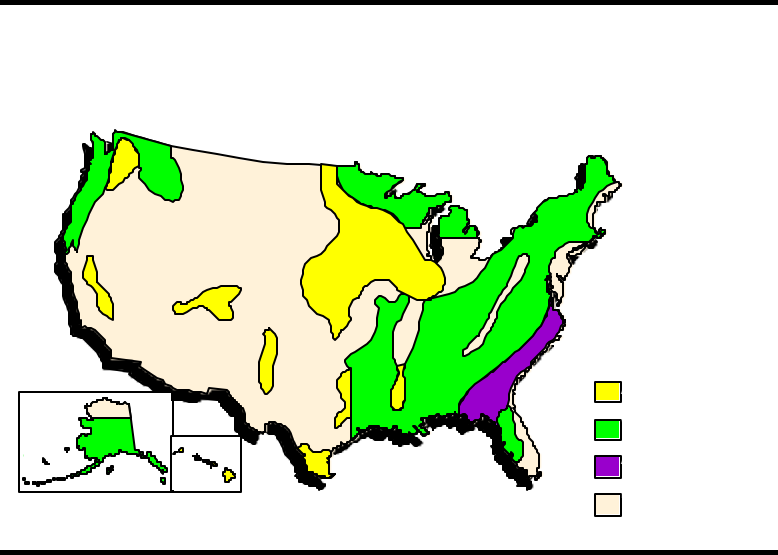
- Wind Energy
- Solar Photovoltaics
- Concentrating Solar Power
- Solar Buildings
- Biomass Electric
- Biomass Transportation Fuels
- Geothermal Energy
- Hydropower
- Solar Advanced Photoconversion

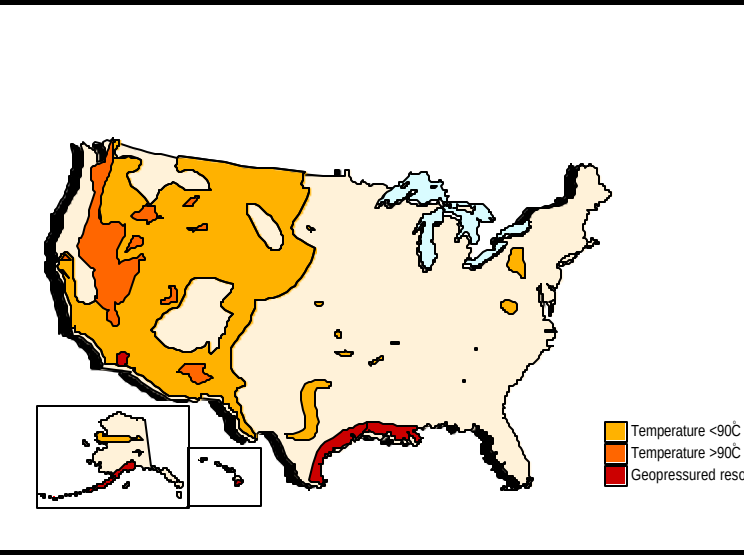
Source: Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions, Oct 1997

U.S. Renewable Energy Resources



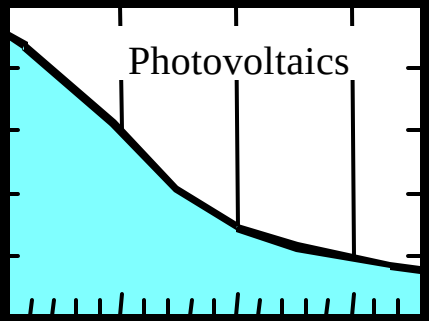


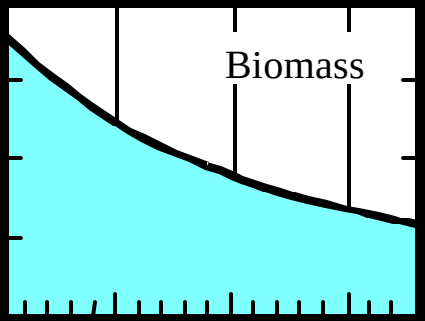


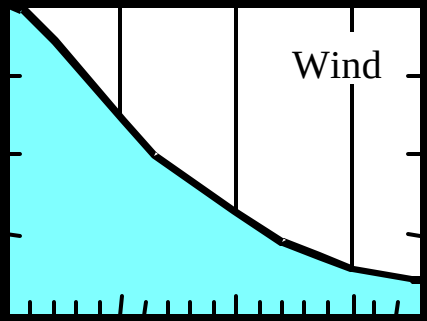


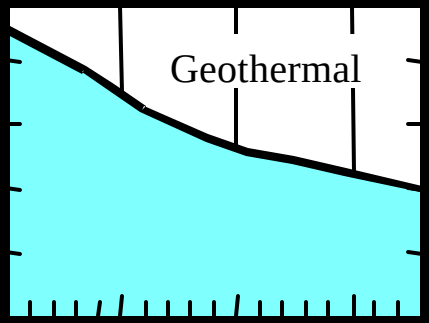
Renewable Energy Technologies

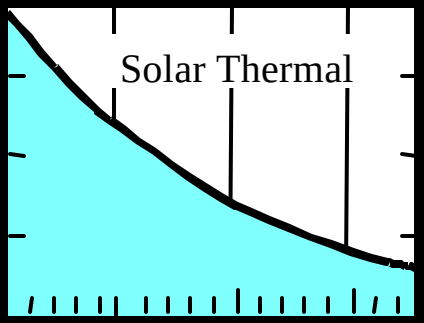
- Zero CO_2 emissions (or net zero for biomass)
- Currently avoids 70 MtC/yr
- Currently accounts for 10% of U.S. energy consumed (hydropower and biomass)

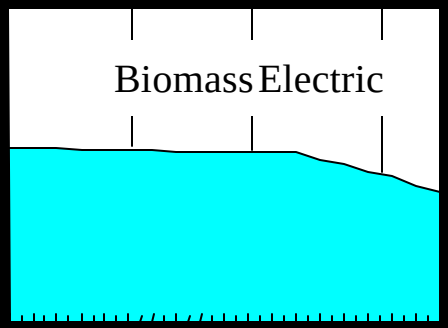












Source: Billman, Advances in Solar Energy submission, 1/8/99

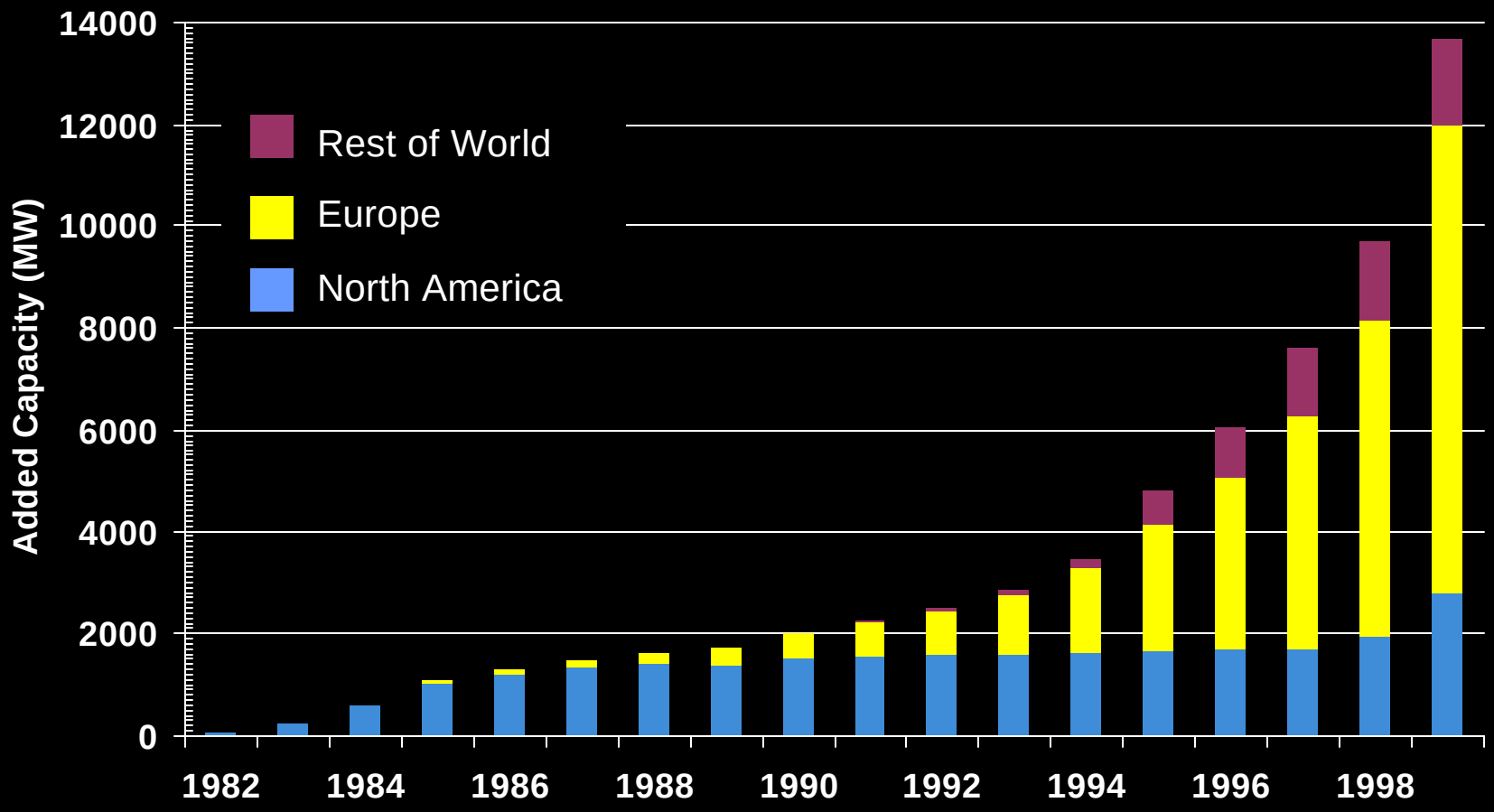
Wind Energy

04824

04690

00263

Worldwide Wind Energy Installations



Based on information supplied by International Energy Agency.

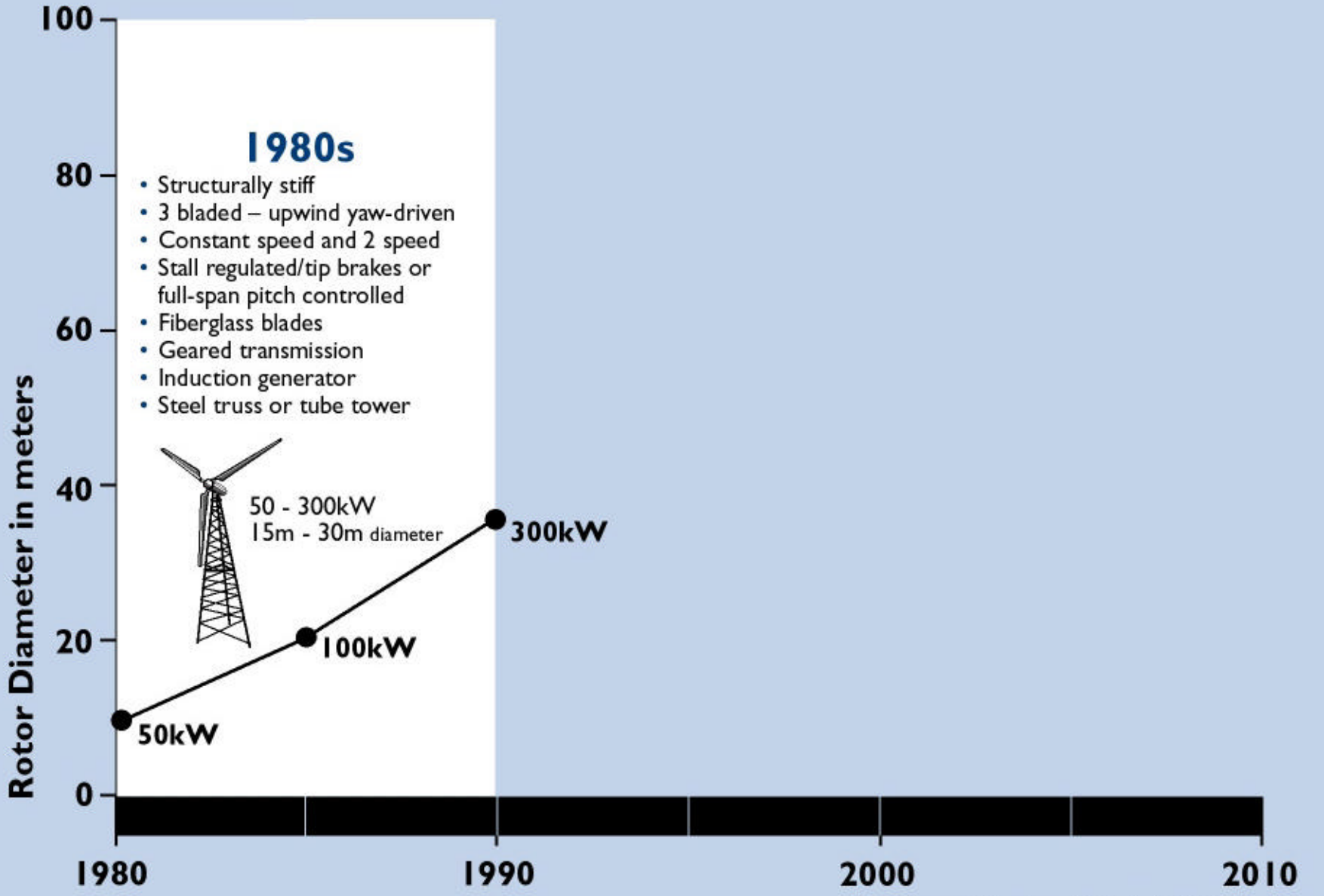
Wind Energy

- 2500 MW installed in U.S., 10,000 MW worldwide
- Current levelized electricity cost is 4-7¢/kWh; 2005 goal is 2-3¢/kWh
- Strong European competition
- R&D: improvements in turbine designs, structural dynamics, lower cost

Green Mountain Power Wind Plant, Vermont (05592)

Source: *Technology Opportunities to Reduce U.S.Greenhouse Gas Emissions*, October 1997

The Evolution of Commercial U.S. Wind Technology



Source: Thresher & Dodge, Wind Energy Journal 1998

The Evolution of Commercial U.S. Wind Technology

1980s

- Structurally stiff
- 3 bladed – upwind yaw-driven
- Constant speed and 2 speed
- Stall regulated/tip brakes or full-span pitch controlled
- Fiberglass blades
- Geared transmission
- Induction generator
- Steel truss or tube tower

50 - 300kW
15m - 30m diameter

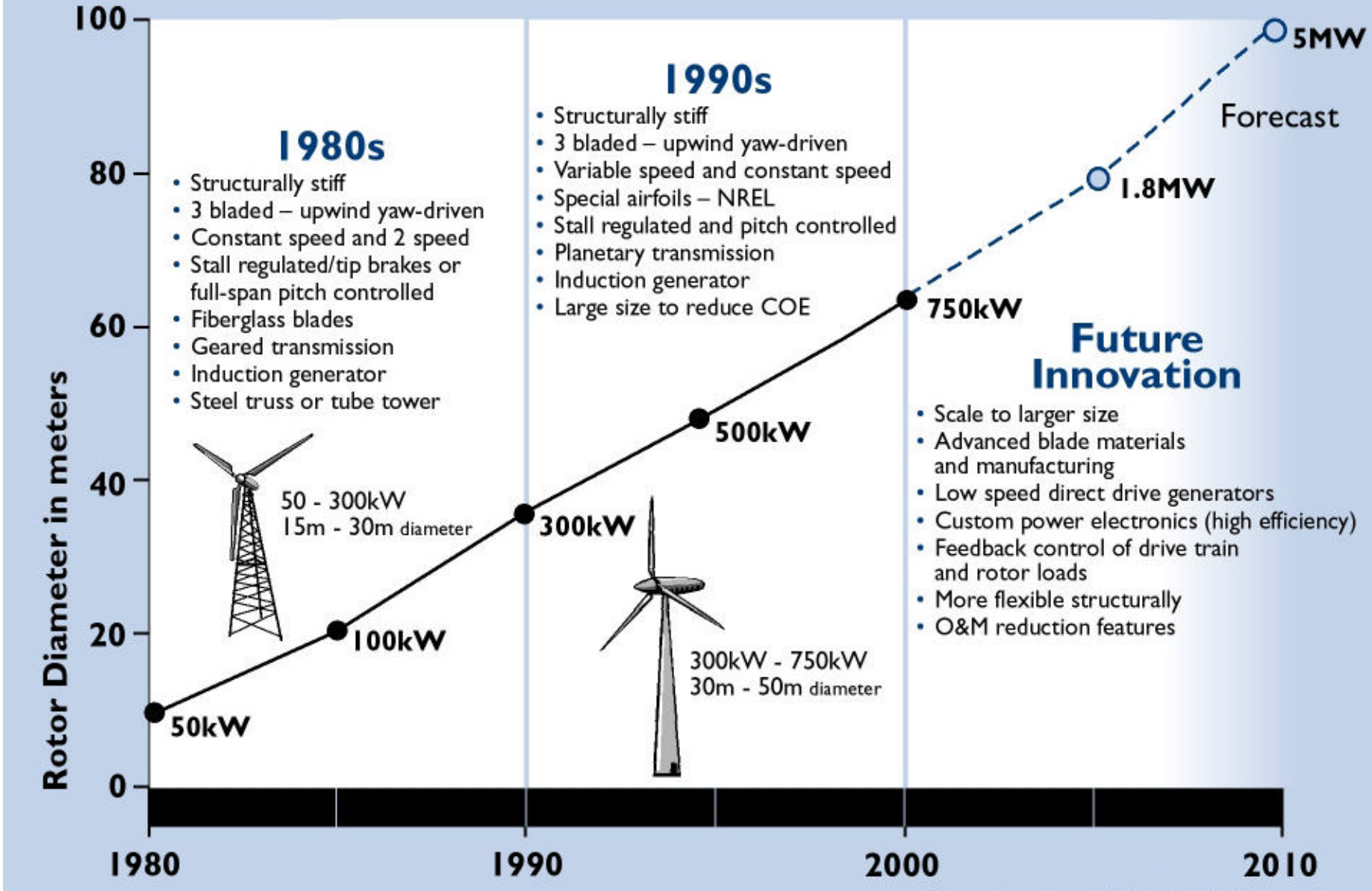
1990s

- Structurally stiff
- 3 bladed – upwind yaw-driven
- Variable speed and constant speed
- Special airfoils – NREL
- Stall regulated and pitch controlled
- Planetary transmission
- Induction generator
- Large size to reduce COE

300kW - 750kW
30m - 50m diameter

Source: Thresher & Dodge, Wind Energy Journal 1998

The Evolution of Commercial U.S. Wind Technology



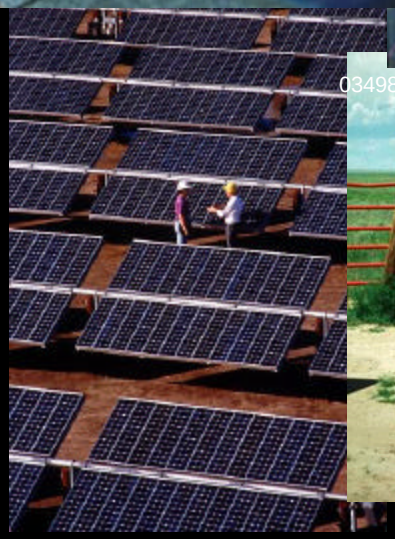
Source: Thresher & Dodge, Wind Energy Journal 1998

Photovoltaics

04566

03498

04876

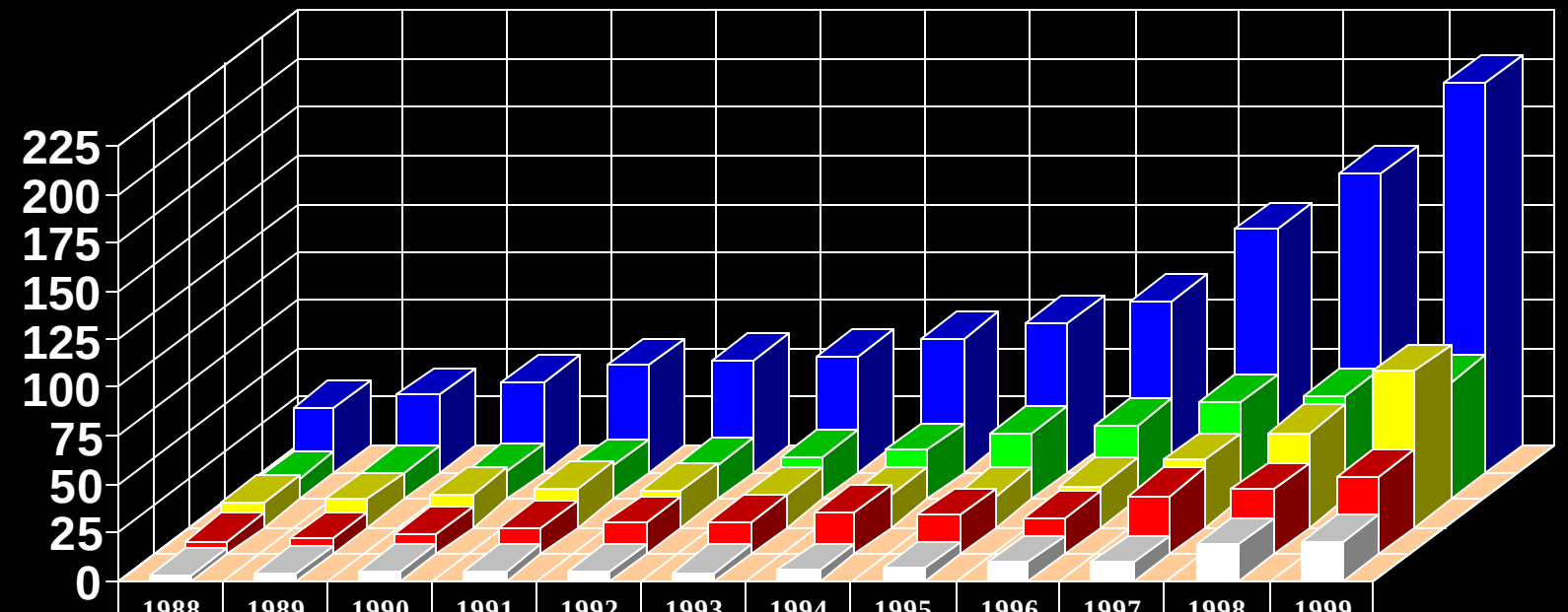


01026

03396

World PV Module Shipments (1988-1999)

(in Megawatts)



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Rest of World	3	4	4.7	5	4.6	4.4	5.6	6.35	9.75	9.4	18.7	20.5
Europe	6.7	7.9	10.2	13.4	16.4	16.55	21.7	20.1	18.8	30.4	33.5	40
Japan	12.8	14.2	16.8	19.9	18.8	16.7	16.5	16.4	21.2	35	49	80
United States	11.1	14.1	14.8	17.1	18.1	22.44	25.64	34.75	38.85	51	53.7	60.8
Total	33.6	40.2	46.5	55.4	57.9	60.09	69.44	77.6	88.6	125.8	154.9	201.3

From PV News, Paul Maycock, editor; yearly February editions.

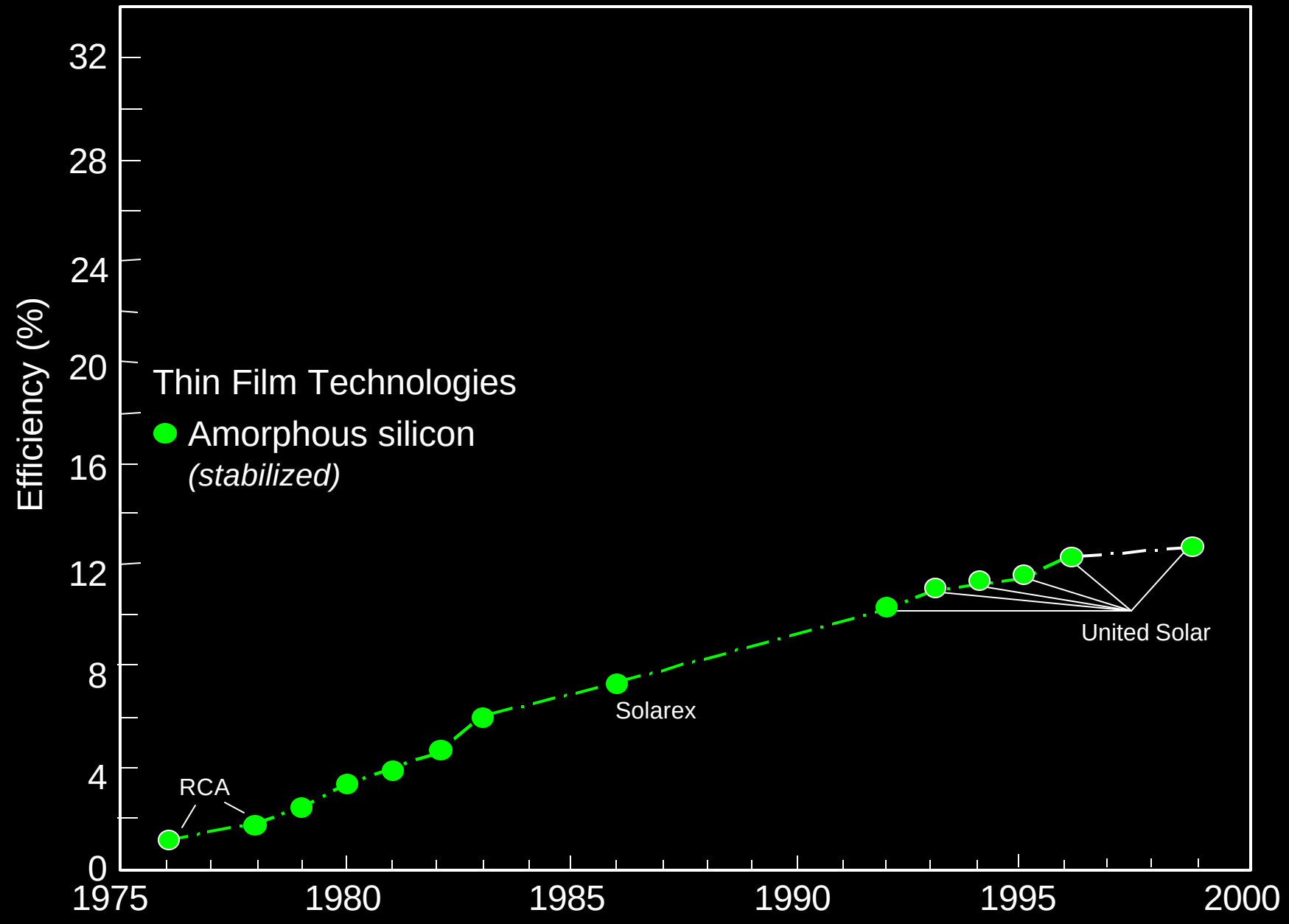
Solar Photovoltaics

- About 500 MW installed worldwide; most remote applications
- 150 MW sales in 1998; 15%-20% per year growth
- U.S. market share 40%
- Strong competition, government support from Japan and Germany
- R&D: fundamental science of materials, advanced solar cells and processes, scale-up, lower cost

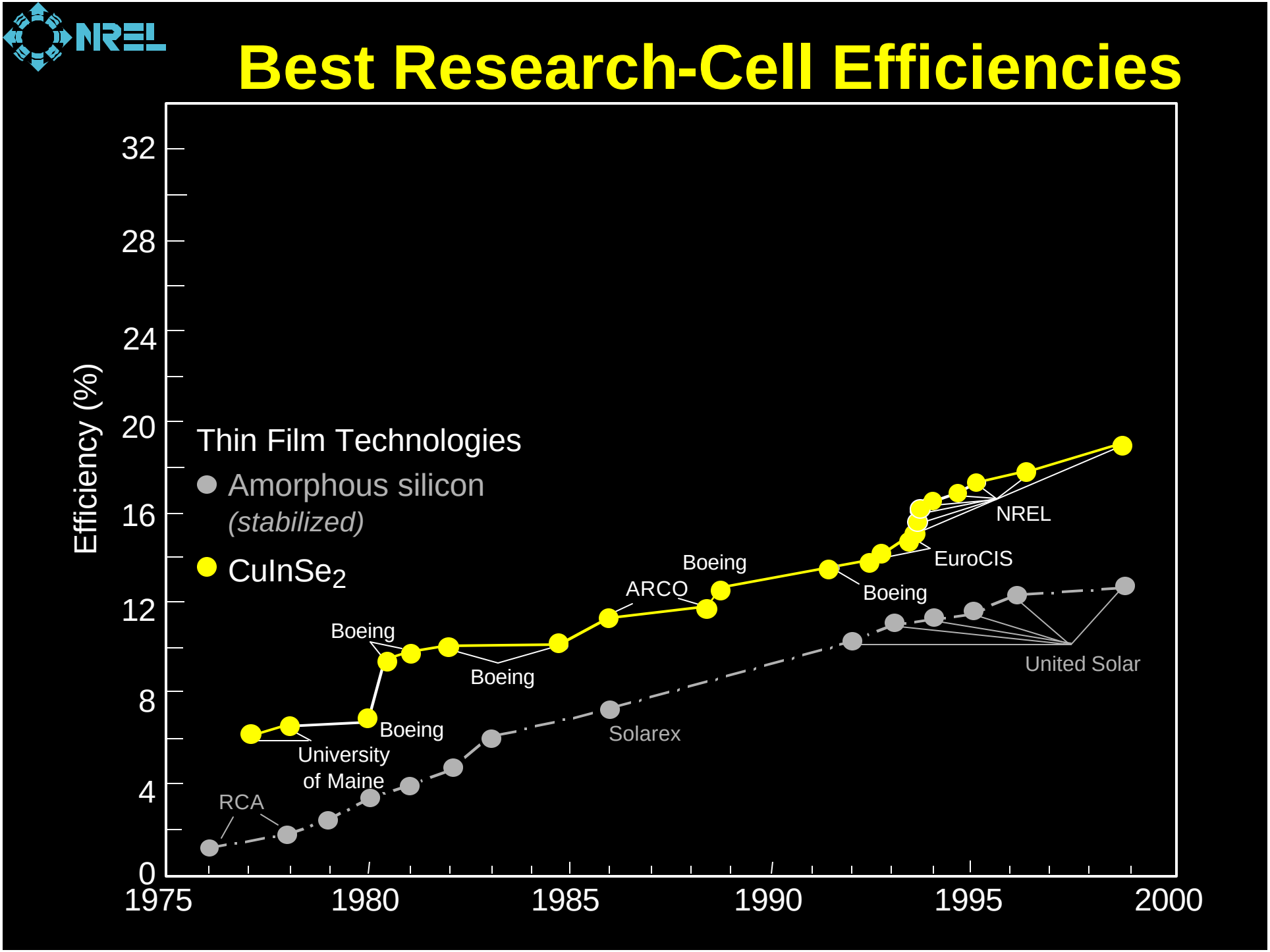
Sacramento Municipal Utility District (01026)

Source: *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions*, October 1997

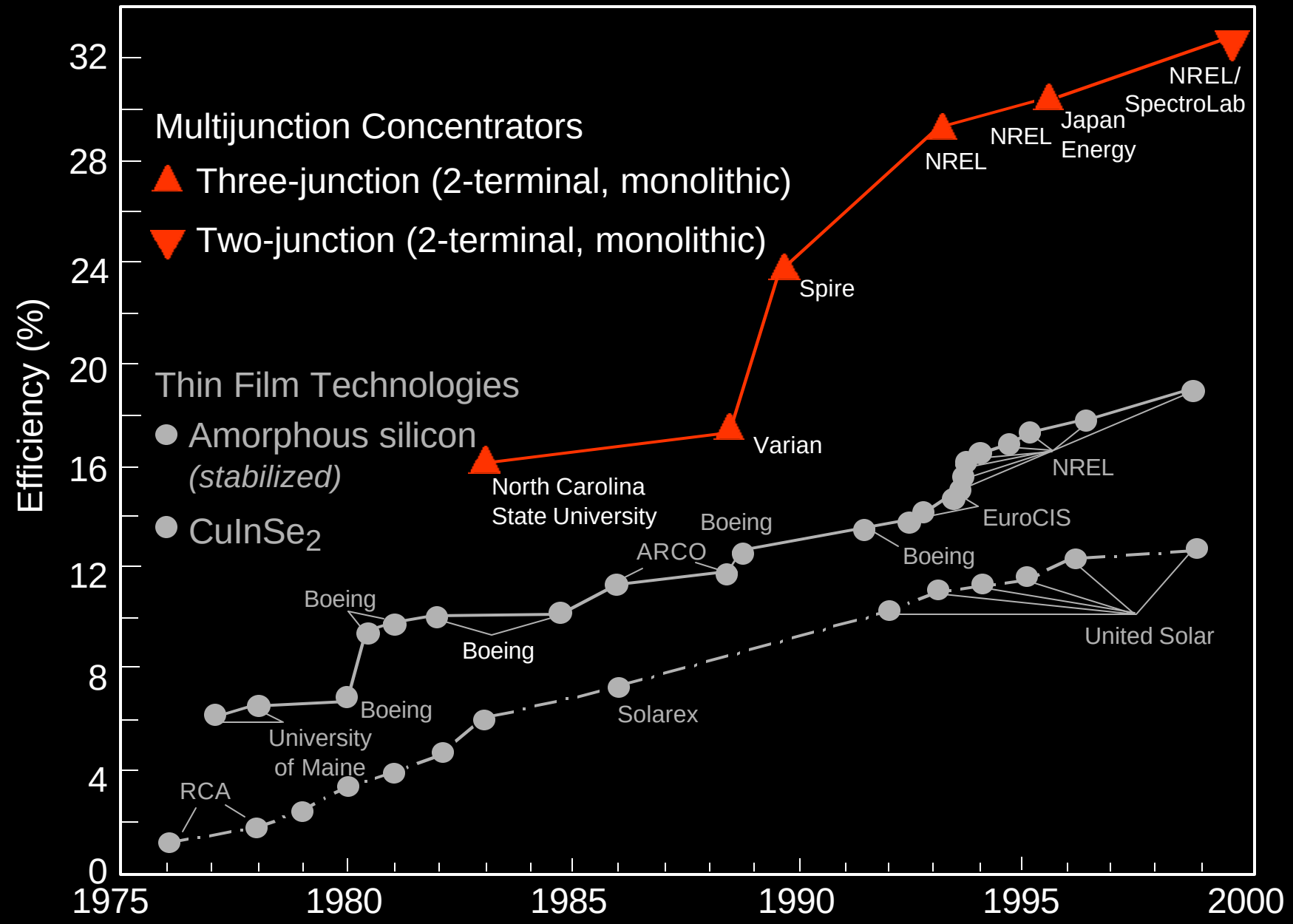
Best Research-Cell Efficiencies



Best Research-Cell Efficiencies



Best Research-Cell Efficiencies



Concentrating Solar Power

Concentrating Solar Power

- Electricity: power tower, trough, dish/Sterling systems
- Current levelized electricity cost is 10–12¢/kWh; 2010 goal is 4–6¢/kWh
- Strong competition
- R&D: improve efficiency, materials, lifetime; lower cost

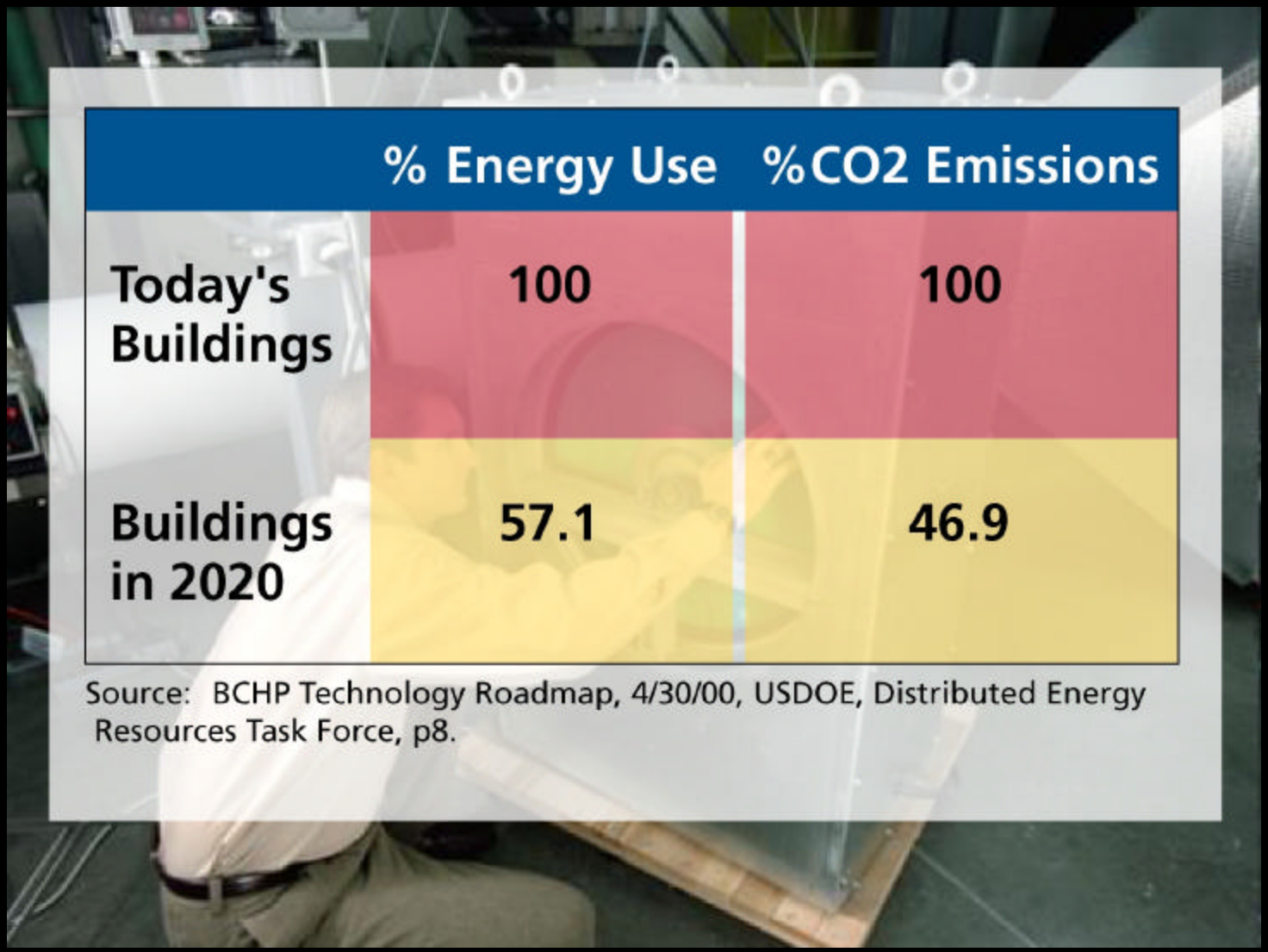
SAIC Stirling Dish Collector 02320

Source: *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions*, October 1997

Solar Buildings

- 4.5 million water heating systems installed; 54 transpired collectors installed worldwide
- Current levelized cost for solar water heating systems is 8¢/kWh; projected 2003 cost is 4¢/kWh; current cost for transpired solar collectors is 2¢/kWh
- Strong international competition
- R&D: improve efficiency, materials, lifetime; lower cost

Buildings of the Future



	% Energy Use	%CO2 Emissions
Today's Buildings	100	100
Buildings in 2020	57.1	46.9

Source: BCHP Technology Roadmap, 4/30/00, USDOE, Distributed Energy Resources Task Force, p8.

Biomass Sources

Poplars

Wood chips

Switch grass

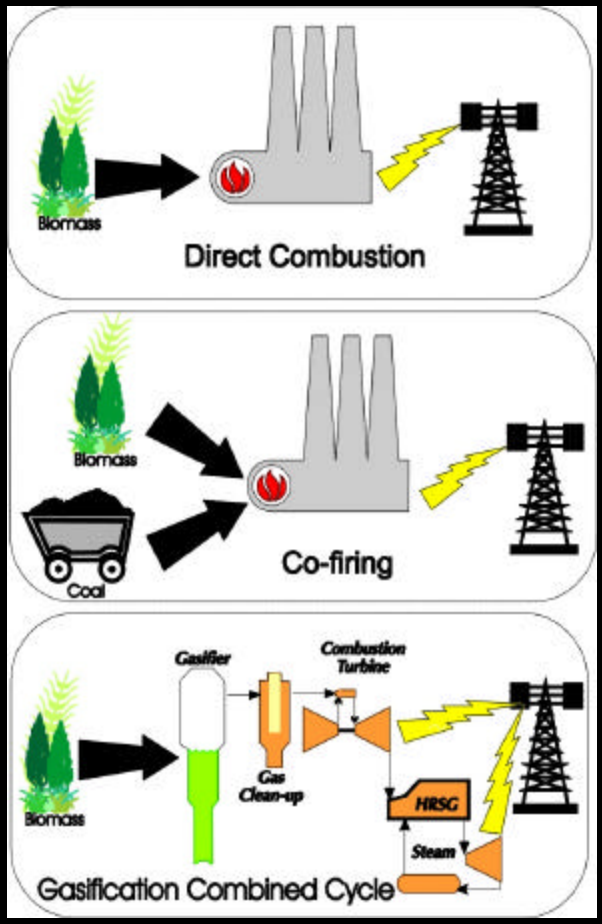
Sugar cane residue

Municipal Solid Waste

Alfalfa

Biomass Electric

- Direct combustion – 7500 MWe installed capacity
- Cofiring (wastes) – demonstrations
- Biomass gasification combined cycle (energy crops) – in development
- Regrowing biomass (energy crops) results in very low or zero net CO_2 emissions
- R&D: ash chemistry and deposition, advanced gas turbine technologies



Source: *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions*, October 1997

Biomass Transportation Fuels

- Ethanol costs:
  - Current: $1.22/gal estimate
  - 2010: $0.67/gal estimate
- Near term - biomass wastes for oxygenates; longer term - energy crops for bulk fuel

- Biochemical and thermochemical processing
- Displacing gasoline with ethanol in light-duty vehicles gives 90% reduction in carbon emissions
- R&D: low-cost production of enzymes, development of microorganisms, improved performance of thermochemical processing, energy crop advances

Source: Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions, Oct 1997

Geothermal Energy

Geothermal Energy

- 6000 MW produced worldwide from reservoirs; 2700 MW from U.S. reservoirs
- Additional 4000 MW capacity for heatpumps in U.S.
- Currently 7-10¢/kWh
- R&D: methods for predicting reservoir performance; low-cost drilling; improved conversion efficiency

Condensers and cooling towers, The Geysers, being fitted with direct contact condensers developed at NREL

Source: Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions, Oct 1997

Stan Bull

Associate Director for Science and Technology

National Renewable Energy Laboratory

1617 Cole Boulevard

Golden, CO 80401

Phone: 303-275-3030

Fax: 303-275-3097

e-mail: stanley_bull@nrel.gov